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VALIDATION AND VERIFICATION (V&V) TESTING ON MIDSCALE FLAME RESISTANT (FR) TEST METHOD

by
Margaret Auerbach
Thomas A. Godfrey
Michael J. Grady
Gary N. Proulx
and
Margaret E. Roylance

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U.S. Army Natick Soldier Research, Development and Engineering Center
Natick, Massachusetts 01760-5000

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14. ABSTRACT
The Midscale Test for FR Performance was developed to complement the capabilities of the *ASTM F1930 Standard Test Method for Evaluation of Flame Resistant Clothing for Protection against Fire Simulations Using an Instrumented Manikin.* Validation and Verification (V&V) testing was carried out to assess the repeatability of the new test method and to compare results obtained from the Midscale test and the F1930. Materials from the Army Air Crew Combat Uniform (A2CU), the Flame Resistant Army Combat Uniform (FRACU) and the Improved Combat Vehicle Coverall (iCVC) were tested using the Midscale apparatus and F1930 testing was performed on all three garment systems for comparison. Comparison of the Midscale flat plate test results with the manikin tests shows that both tests predict second degree burn injury (depth of burn between 75 and 1200 µm) according to the F1930. The injury prediction from the Midscale cylindrical test form was higher, with third degree burns predicted for all systems/materials. The results demonstrated that the Midscale test is a quick and cost-effective method for evaluation of FR performance of design features or for observation of material behavior in a flame engulfment scenario.

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FLAMES	PROTECTION	FLAMMABILITY	THERMAL PROPERTIES
FABRICS	COMBUSTION	TEST METHODS	TEST AND EVALUATION
SENSORS	VALIDATION	BURNS(INJURIES)	FLAME RESISTANT CLOTHING
TEXTILES	HEAT FLUX	HEAT FLUX SENSORS	CONVECTION(HEAT TRANSFER)
MANIKINS	VERIFICATION	RADIANT HEAT FLUX	V&V(VERIFICATION AND VALIDATION)

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Executive Summary

The Midscale Test for Flame Resistant (FR) Performance was developed by the Natick Soldier Research, Development and Engineering Center (NSRDEC) to complement (not replace) the capabilities of the *ASTM F1930 Standard Test Method for Evaluation of Flame Resistant Clothing for Protection against Fire Simulations Using an Instrumented Manikin.* At half the cost of the F1930, it provides a cost-effective test method for assessing performance of standard and novel FR materials and design configurations during fire engulfment. Details of the test method and its development can be found in the NSRDEC Technical Report *Development of a Midscale Test for FR Protection*.

After the Midscale apparatus was completed and a draft Midscale test method had been balloted by ASTM, Project Manager Soldier Protection and Individual Equipment (PM-SCIE) requested Validation and Verification (V&V) testing to assess the repeatability of the new test method and to elucidate the relationship between results obtained from the Midscale test and the F1930. The PM selected FR materials from the Army Air Crew Combat Uniform (A2CU), the Flame Resistant Army Combat Uniform (FRACU) and the Improved Combat Vehicle Coverall (iCVC) for testing using both a flat plate and cylindrical Midscale test form. F1930 manikin testing was performed on all three garment systems for comparison. Testing was performed from January to April 2015.

The results show that sensor to sensor variation in incident heat flux is significantly lower for the Midscale test than for the F1930 manikin test, where it must be less than +/- 21 kW/m^2 from 84kW/m^2. The standard deviation in incident heat flux measured during the V&V testing is +/- 3.72 kW/m^2 for the flat plate and +/-10.92 kW/m^2 for the cylinder. Greater uniformity in incident heat flux means that comparing the performance of FR fabrics is easier. Fabric to fabric comparison is made even clearer when alternate measurements of performance such as predicted depth of burn, transmitted fluence and Energy Transmission Factor (ETF) are used to assess material performance. Transmitted fluence and ETF are used in the ISO 13506 Standing Manikin FR test.

Comparison of results for the different test methods shows that the Midscale flat plate test and the selected manikin sensors both predicted second degree burn injury (predicted depth of burn between 75 and 1200 μm). Predicted depth of burn is higher in the flat plate test than the manikin, indicating a more severe second degree burn. Use of the Midscale flat plate would therefore provide a conservative prediction of the burn injury protection of a new fabric in comparison to the manikin. The differences in predicted burn injury for different test methods reflect the differences in air gap between the fabric and the sensors in the different tests. The thickness of the insulating air gap is known to have a significant effect on depth of burn and burn injury in other standard FR tests. Air gap thickness is minimized and the predicted burn injury is highest in the cylinder version of the Midscale test where the fabric is clamped around the cylindrical form, producing the effect of a tight fitting single layer garment.

VALIDATION AND VERIFICATION (V&V) TESTING ON MIDSCALE FLAME RESISTANT (FR) TEST METHOD

1. Introduction

This report covers the performance of Validation and Verification (V&V) testing from January to April 2015 on the Midscale Flame Resistant (FR) test method that was developed by the Natick Soldier Research, Development and Engineering Center (NSRDEC) to complement the *ASTM F1930 Standard Test Method for Evaluation of Flame Resistant Clothing for Protection against Fire Simulations Using an Instrumented Manikin* [1]. Details of the Midscale test development can be found in the NSRDEC technical report *Development of a Midscale Test for FR Protection* [2].

Current ASTM F1930

While the F1930 [1] is widely used to predict performance of FR ensembles, the test method has several limitations. Results for each laboratory may exhibit acceptable reproducibility, but previous inter-laboratory testing has shown that the lab to lab variability in the F1930 test and in the parallel international standard ISO 13506 is very high. As stated in the F1930 Precision and Bias statement, the reproducibility limit from lab to lab is higher than 50% for some garments, raising concerns in the testing community on the validity of the F1930 as a standard test method.

As more laboratories world-wide have begun to perform the F1930 or the ISO13506, several other limitations of the F1930 have become apparent. Prediction of burn injury in the F1930 uses measured transmitted heat flux as a function of time, then employs a mathematical model of the three layers of the human skin (epidermis, dermis and subcutaneous) to calculate predicted depth of burn as a result of the incident heat flux. This depth of burn is then binned as negligible, second (within the dermis) or third degree burn (full skin thickness). Since the dermis accounts for about 90% of the skin thickness, reporting only second or third degree burns puts superficial second degree blisters in the same category as near full thickness burns.

Reporting the predicted depth which the burn injury reaches provides better detail about the nature of the predicted burn injury than only identifying second or third degree burns, but this calculated depth of burn is still based on the skin thickness values shown in the burn injury model in Figure 1. Actual thicknesses of the three layers of the skin vary from place to place on the body and a more accurate prediction of burn injury at a specific location on the body must be based on skin thickness at those locations. Determination of representative skin thicknesses on the head or hands and development of more biofidelic burn injury models reflecting that realistic physiology should be a goal of future research and development.

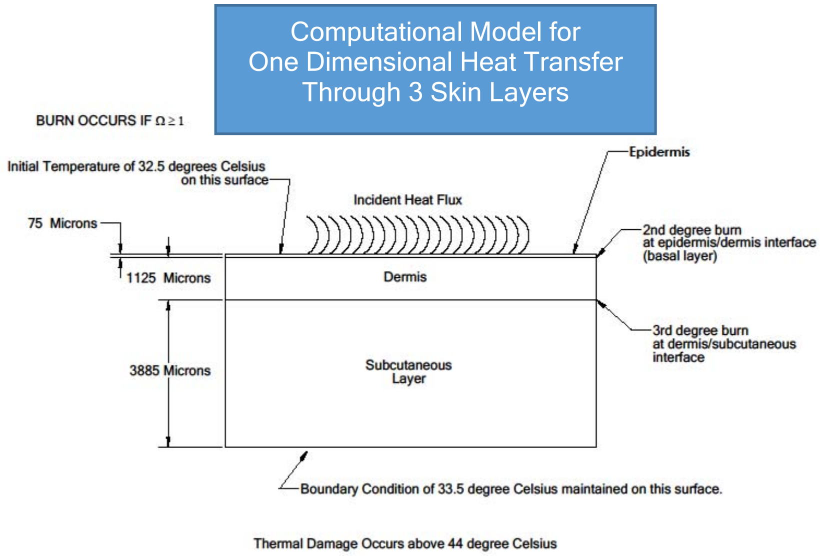

Figure 1. Illustration of the ASTM F1930 burn injury model

A significant amount of detailed information about the nature and local surface distribution of the potential burn injury in the F1930 test is also lost by distributing sensors so they are able to sample only a small portion of the manikin surface. For example, 123 manikin heat flux sensors may be distributed, roughly equally over the body surface, excluding the hands and feet. The F1930 test method requires a minimum of 100 sensors [1]. If copper slug sensors are used, the responsive element in each sensor is 1.27 cm in diameter, and as such, the device measures heat flux over a very small element of the manikin surface (i.e., the area of the copper disk, 1.267×10^{-4} m^2). The area of the sensing element in other sensor types is similar to the copper slug. In fact, though a large number of sensors is employed, a comparison with the total sensor area with typical numbers for body surface area (1.62 m^2 excluding hands and feet) reveals that the sensors are sampling a little less than 1% of the manikin surface.

In garment tests, however, garment design features vary with position, and the response of the garment is not uniform over the large surface areas in between sensor locations. The predicted body burn from the F1930 is calculated from data on widely separated sensors using a burn injury model that is validated against a very limited number of superficial second degree human burn injuries on the forearm. Depending on the garment design, there are therefore critical localized effects which are not detected in the response of the sparse sensor array and the burn injury model does not take into account the variation in the skin physiology across the surface of the body [3].

In the referenced study, one example of local effects missed due to limited (less than 1 %) sensor surface coverage occurred during the testing of prototype combat shirts designed to provide moisture management under ballistic vests. Visual observation indicated that the nylon zippers, located down the upper quarter of the center front, were melting to the manikin surface. Since there were no sensors located on the manikin in this area to measure the transmitted heat energy,

the melting of the zipper was not measured or reflected in the predicted F1930 burn injury. Based on these results, the zipper was redesigned with a facing between the zipper and skin to prevent burn injury, and in this instance a sensor was also added to the NSRDEC manikin at the location of the zipper. It is not possible, however, to modify the manikin by adding a sensor every time such an injury is indicated by visual observation.

A representative cost of an F1930 test might be $2500 for the first test and $500 for each additional test in the series. By comparison, the NSRDEC performs the Midscale test for $1250 for the first test and $125 for additional tests – half the cost of the F1930. If information on FR performance of novel fabrics or changes in design details (pockets, etc.) in a realistic fire engulfment scenario is all that is required, the Midscale test can be performed on the fabric or the design detail itself without the approximate $500-1000 cost of manufacturing a garment. Use of the Midscale as a design tool or for material evaluation would therefore be preferable to the F1930 from a cost point of view.

The high variability from the nominal 84 kW/m^2 incident heat flux across the surface of the manikin during testing is due both to the chaotic nature of combustion, especially during fire engulfment, and the static pose of the manikin during the heat exposure. This variation in incident heat flux subjects the material at different locations in the garment to different thermal threats, making it difficult to ascertain differences in material performance using the F1930. The difficulty in assessing design details using the F1930 arises from the fact that less than 1% of the manikin surface area is covered with sensors. Therefore, local effects are certainly missed, and it is likely that areas of high possible burn injury will not be captured in the F1930 data [3].

The existence of high lab-to-lab variability in the F1930, which has been documented in the ASTM standard itself, suggests to the testing community that some aspects of the test are not well understood or controlled. This concern gave rise to the formation of the ISO 13506 project group to improve the parallel international method. This project group has undertaken round robin testing involving 12 test labs around the world. The objective of this ISO study is "to understand the differences and similarities in the way the test is conducted in different labs and therefore to improve the repeatability and reproducibility of the manikin systems worldwide. It is not to criticize individual labs or technologies" [4]. Results of the round robin testing, including identification of likely sources of errors or lab-to-lab differences and initial recommended changes to the method are available from ISO [4]. Further testing and recommendation are expected as the work of the project group continues.

To summarize, although there is no alternate to the F1930 for full garment assessment, the test has a number of limitations. They include high testing cost, high variability of incident heat flux across the surface of the manikin, low surface coverage of the heat flux sensors and a high level of lab-to-lab variability.

Development of the Midscale FR Performance Test

In an effort to address some of the limitations of the F1930, NSRDEC proposed a project to develop a Midscale test method that would use the same heat flux as the F1930 with a simple flat plate or cylindrical test fixture to provide an indication of results that will be seen during full manikin testing (see the Technology Transition Agreement (TTA) in Appendix A) at half the cost of the full scale test. New candidate FR materials could be evaluated under realistic flame engulfment conditions without the expense of fabrication of an entire ensemble for each test. The smaller area of the Midscale test specimen compared to the manikin would allow greater control of the standard target value of 84 kW/m^2 heat flux and much higher density of sensors per unit surface area to provide much richer information on the FR performance of design details. The Midscale test employs a larger fabric specimen than swatch-level tests such as the *ASTM D6413 Standard Test Method for Flame Resistance of Textiles (Vertical Test)* or Vertical Flame test and the Thermal Protection Performance (TPP) test. It also allows the incorporation of design details not accommodated by swatch-level methods.

Although second and third degree burn injuries are predicted at each Midscale sensor using a burn injury model identical to the F1930, other ways of reporting those same data are also used to provide better understanding of the material performance and predicted burn injury. Calculated depth of burn is reported, and can be used to differentiate between superficial and severe second degree burns when a second degree burn is predicted. Transmitted fluence and Energy Transfer Factor (ETF) are also reported at each sensor. These values are used in the ISO 13506 test to predict FR material performance.

Transmitted fluence is a measurement of the total heat energy transmitted through a protective fabric to the manikin or test form surface during the 4 s exposure, and is a good indication of protective performance of the material. Its use eliminates dependence on a physiologically inaccurate burn injury model and avoids the increased error which is observed when the value of transmitted fluence is run through the burn injury model calculation to predict depth of burn and burn injury. ETF is the transmitted fluence after a 4 s exposure normalized by the total heat energy deposited on a bare surface during the same period. It therefore provides a good direct indication of relative performance of various protective materials. ETF is discussed in greater detail in Chapter 5.

As part of the NSRDEC Collaborative Science and Technology (S&T) Planning (CSTP) process, this proposal was presented to Program Executive Office (PEO) Soldier and Training and Doctrine Command (TRADOC) at a PEO-Soldier Prioritization Review in Spring 2010. It was selected by PEO-Soldier for support from NSRDEC core S&T funds and the NSRDEC FY11 budget was realigned to support the effort. A TTA, included in Appendix A, was signed by NSRDEC and PM-SCIE in September 2010 to document the agreement. The TTA called for the Midscale testing capability to be available to PM-SCIE at NSRDEC by the end of FY13. The Midscale test apparatus and a draft ASTM standard test method for use of the apparatus were available at NSRDEC on schedule as agreed in the TTA.

Objectives of the V&V Testing

The PM-SCIE requested the V&V testing as part of the activities of a Capability Integration Team (CIT) which was formed at the request of the NSRDEC TTF after the completion of the NSRDEC CSTP TTA deliverables. One objective of the CIT was to address any further questions or concerns the PM had about the Midscale test method. The PM expressed a desire for V&V data to demonstrate the repeatability of the Midscale test and correlation between results obtained from the Midscale and the F1930.

The primary goals of NSRDEC were to provide V&V data to the PM as requested and to collect information for the next draft of the ASTM standard Midscale test method. In particular, the information will be used to set the acceptable variation in incident heat flux for the flat plate and cylindrical test forms and to prepare a Precision and Bias statement.

2. V&V Test Plan

Materials Selected for the V&V Testing

The V&V test plan was developed in collaboration between the NSRDEC and PM-SCIE. The PM selected the materials that were included in the V&V test matrix. The initial set of materials chosen exhibited limited variation in FR performance. NSRDEC agreed to an initial group of three materials to be tested, but plans to continue the testing after the completion of the formal V&V to augment the data with materials exhibiting a greater range of performance which would be necessary for a precision and bias statement. The V&V test matrix is shown in Table I.

The three FR systems/materials selected for evaluation by the PM were the Army Air Crew Combat Uniform (A2CU) (National Stock Number (NSN) 8415-01-583 -9212 for the coat and NSN 8415-01-583-9308 for the trouser), the Flame Resistant Army Combat Uniform (FRACU) (NSN 8415-01-599-0485 for the shirt and NSN 8415-01-598-9860 for the trouser) and the Improved Combat Vehicle Coverall (iCVC) (NSN 8415-01-583-8910). The A2CU fabric is Nomex IIIA (92% Nomex, 5% Kevlar and 3% carbon based anti-static P140). The Defender M Type III fabric employed in the FRACU is a ripstop fabric blend of 65% FR rayon, 25% para-aramid and 10% nylon. The iCVC material is Nylon/Cotton/Nomex. All three selected fabrics were considered FR and designed to prevent serious predicted burn injury in the F1930.

Table I
V&V Test Matrix

Uniform	Material	Midscale Cylinder (# of Samples)	Midscale Flat Plate (# of Samples)	ASTM F1930 (# of Samples)
FRACU	Defender M Type 1	18	18	6
A2CU	Plain Weave Nomex	18	18	6
iCVC	Abrams Lite	18	18	6
	Totals	54	54	18

V&V Test Conditions

All garments, fabrics and underwear were tested after laundering once as specified in ASTM F1930. Each specimen was conditioned for at least 24 h at 70 ±5 °F (20 ± 2 °C) and 65 ± 5 % relative humidity and tested within 30 min of removal from the conditioning area. Testing was randomized and run over a period of several weeks to determine reproducibility of the test data. The general approach employed was to select a material/system and rotate it through the three test methods. Since many more Midscale than manikin tests were performed due to the limited number of full garments (six for each garment type) supplied by the PM for testing, it was not possible to maintain that order throughout. The test dates are included in the table in Appendix B. In order to ensure that the propane supply was at full pressure, a pause of at least 15 min was observed after the completion of each test before beginning a new test.

All F1930 tests were run at 84 kW/m^2 incident heat flux as specified in the test method. The exposure duration was 4 s. The same test conditions were used for all the Midscale flat plate and cylinder tests. All the materials tested in the Midscale flat plate and cylinder tests consisted of a single layer of fabric. Data chosen from the manikin for comparison were therefore selected from sensors in areas of the manikin with a single layer of fabric. One consideration in choosing only locations with a single layer of fabric is that a double layer of fabric, such as that found at pockets or over an undergarment, provides sufficient protection in most cases to prevent second degree burns. Due to the nature of the burn model discussed in the Introduction and shown in Figure 1, in the absence of second degree burns the F1930 predicts no effect. Although depth of burn, transmitted fluence or ETF will provide a basis for comparison of the performance of two layers of these systems/materials, they are not normally reported for a manikin test.

Midscale Data Reported in the V&V

To assist in comparing FR performance of different materials, Midscale test data include F1930 data such as predicted % burn injury along with other quantities not generally reported in the F1930. All Midscale and F1930 data are based on the same transmitted heat flux measured at each sensor as a function of time during the 4-s exposure. Although the F1930 % burn injury is determined from the calculated depth of burn (as discussed in the background section and illustrated in Figure 1), depth of burn itself is not customarily reported for the F1930. In the Midscale test, depth of burn calculated according to the F1930 burn injury model is reported. Reporting depth of burn provides additional context for the F1930 designation of second or third degree burn, since depth of burn provides a continuous indication of the severity of the predicted injury, including low level first degree burns and gradations of severity of second degree burns.

In addition to depth of burn, V&V data reported also include transmitted fluence and ETF at each sensor. All of these quantities are calculated from the same transmitted heat flux data at each sensor as a function of time. Transmitted fluence is the integral of the heat flux vs time history, which results in a total heat energy per unit area imparted to the surface of the cylinder, flat plate or manikin at that sensor during the 4-s exposure. It provides a continuous indication of the severity of injury but does not depend on a burn injury model as does the depth of burn. ETF is calculated at each sensor as the ratio of the transmitted fluence to the value of nude fluence measured during calibration. The value of ETF, like the transmitted fluence, does not depend on a burn injury calculation and is a normalized measurement of fabric performance.

ETF

- Is the ratio of the transmitted fluence to the fluence on the sensor during a “nude” calibration burn (this nude value varies with position)
- Varies from 0 to 1 corresponding to the amount of incident heat energy transmitted to the sensor. A value of 1 means the fabric provides no protection at that point and a value to 0 corresponds to 100% protection.
- Is a direct, linear continuous measurement of comparative fabric performance, independent of any skin burn injury model

- Is reported in the ISO13506-1 instead of % predicted burn injury

All these data are shown in full in Appendix B, and the results are summarized in Tables II through IV and in Figures 6, 8 and 9 in the next chapter.

3. Methods Employed in the V&V

For each of the three test geometries studied (Midscale flat plate, Midscale cylinder and manikin), the heat flux transmitted through the garment or fabric as a function of time was recorded for each sensor in the test form for a total of 120 s. This time interval included a few seconds before the burn was initiated, the 4 s of the burn and more than 100 s after termination of the burn. It is necessary to continue monitoring heat flux after the incident exposure is terminated because heat energy stored in the garment can increase the severity of the predicted burn injury during that time. Depth of burn and predicted burn injury were then calculated at each sensor using the F1930 burn injury model.

For the 13x13 inch flat plate test form, shown in Figure 2, there are a total of 13 sensors. 12 heat flux sensors are evenly placed around the center of the plate with a Medtherm Schmidt-Boelter Thermopile Sensor (not water cooled) in the center. Figure 3 shows the arrangement of the sensors in the cylindrical heat form. The cylinder contains 23 sensors arranged in alternating columns of 5 sensor and 4 sensors each. This sensor pattern reproduces the sensor spacing on the manikin.

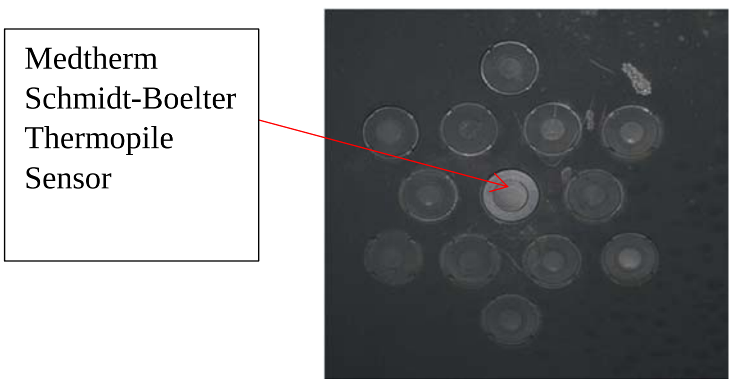

Figure 2. 13 inch x 13 inch flat plate form

Figure 3. Cylindrical test form

Figure 4 shows the mean incident heat flux measured at each sensor during representative nude calibration burns. Nude calibration burns are performed as the first and last test each test day and after a break in testing, if one is taken. Channels shown in red are >5% higher than the mean, and channels shown in blue are >5% lower than the mean. The standard deviation in heat flux is 3.72 kW/m^2 for the flat plate and 10.92 kW/m^2 for the cylinder. The higher variability from sensor to sensor in the cylinder test than the flat plate probably reflects the larger size and more complex geometry of the cylindrical test form. These values for the Midscale flat plate and cylinder may be compared to the F1930 standard, which requires that the calculated heat flux standard deviation is not greater than 21 kW/m^2. Variability in the incident heat flux is half of the manikin value for the Midscale cylinder and less than one fifth of the manikin value for the Midscale flat plate.

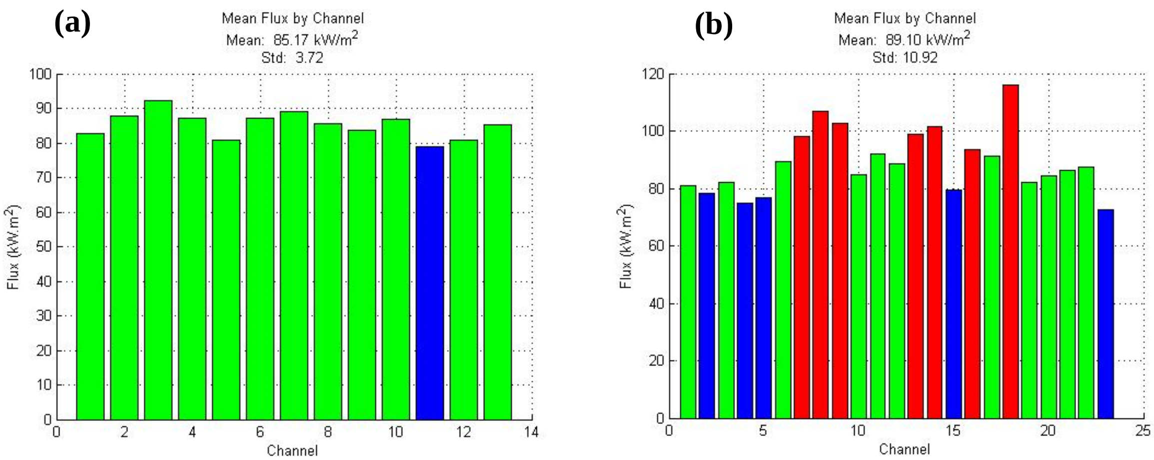

Figure 4. Representative incident heat flux variability measured on the Midscale test forms. (a) Flat plate test form; (b) Cylindrical test form

The manikin tests were all performed according to F1930 with transmitted heat flux measured at all sensors, but for each ensemble the manikin data were filtered to eliminate all but selected sensors at locations on the manikin with only one layer of fabric. Calculation of depth of burn and % burn injury for all the manikin results were based on only the selected sensors for each garment as shown in Figure 5.

The location of the selected sensors was different for each garment due to differences in the design. In general the sensors covered by only a single layer of fabric were on the lower legs and arms below the undershirt sleeves. It should be noted that all the garments are loosely fitted in all these areas. The selected sensors for each garment are indicated light blue in the sensor maps shown in Figure 5. Figure 5a shows sensor map for the A2CU, Figure 5b for the FRACU and Figure 5c for the iCVC.

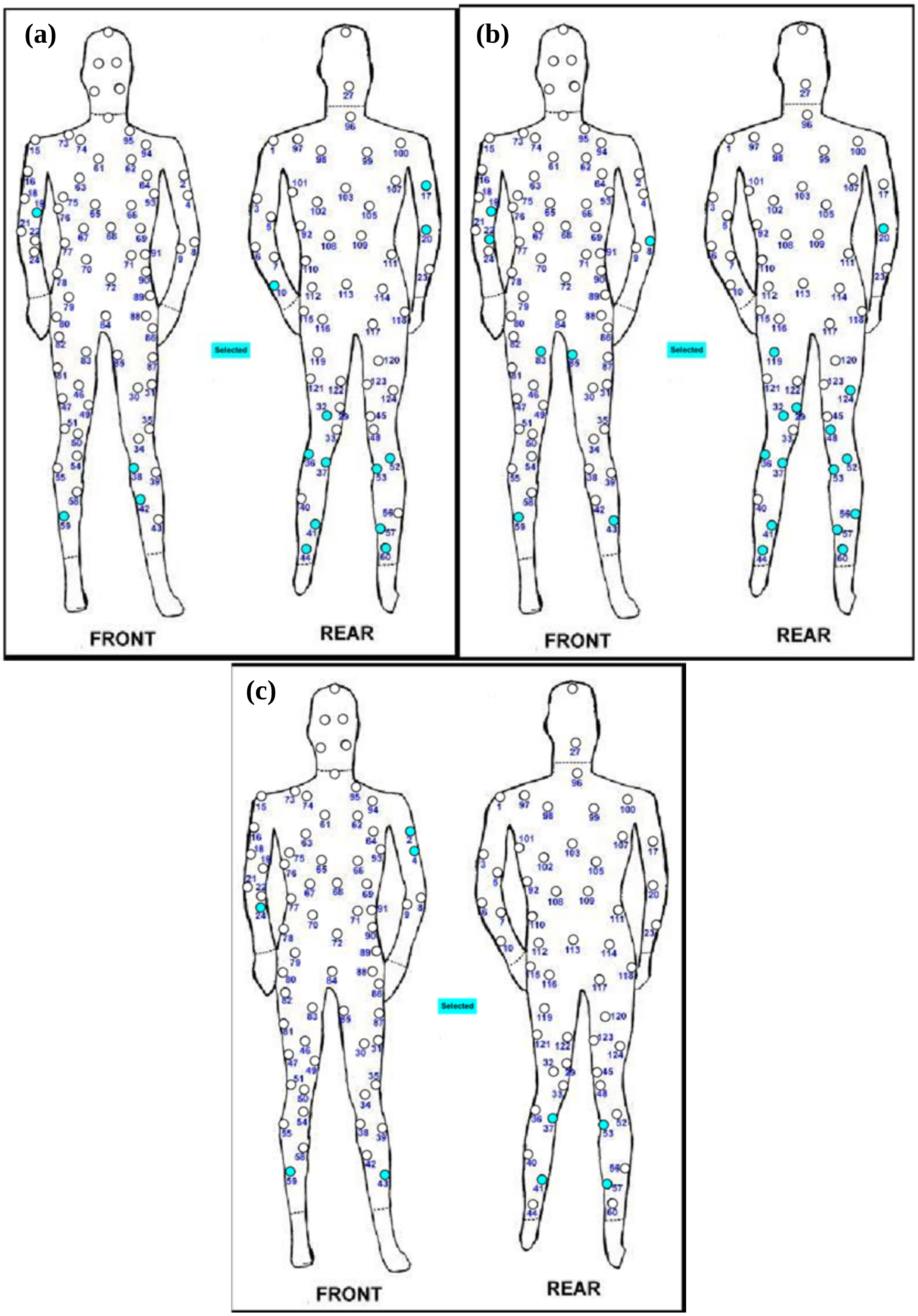

Figure 5. F1930 sensor maps. (a) Sensor map showing 16 selected sensors on the A2CU; (b) Sensor map showing 22 selected sensors on the FRACU; (c) Sensor map showing 9 selected sensors on the iCVC

4. Results and Discussion

Discussion of data summaries

Table II and Figure 6 display the average depth of burn and predicted burn injury as a function of test method and system/material taken from Appendix B. The line in Figure 6 indicating predicted second degree burn is shown in yellow and represents the depth of the epidermis at 75 µm. Any value of depth of burn deeper than 75 µm but less than 1200 µm (depth shown in red) is classed as a second degree burn.

Table II
Average Depth of Burn in µm

	Depth of Burn (µm)		
	Flat Plate	Cylinder	Manikin
A2CU	596.4	1443	364.0
FRACU	622.1	1430	114.3
iCVC	723.5	1334	362.5

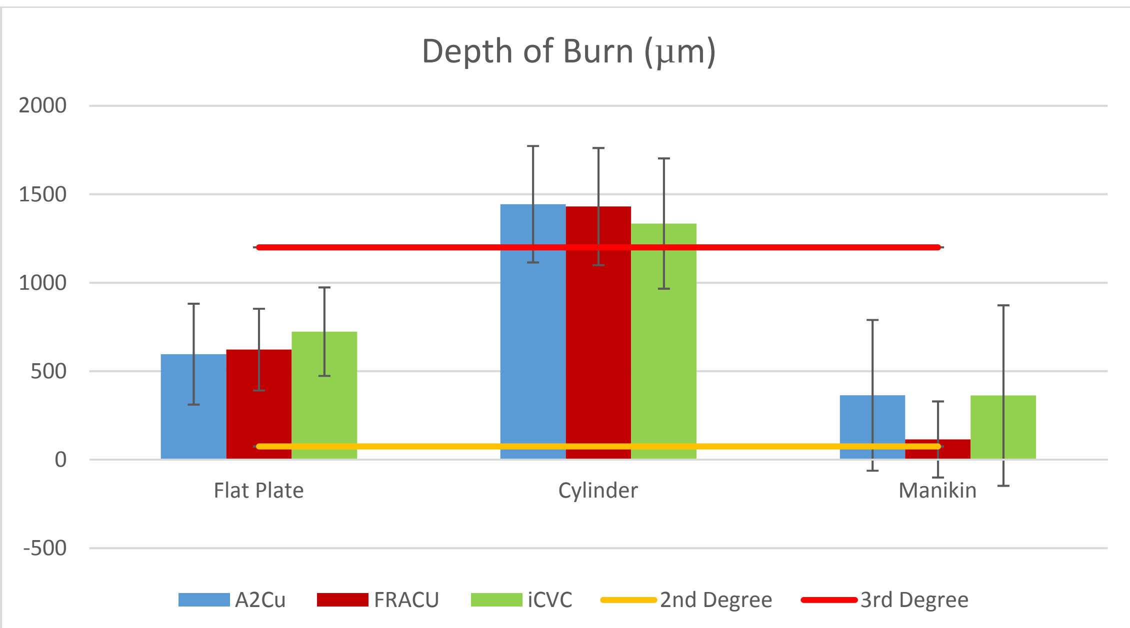

Figure 6. Average depth of burn in µm with onset of 2^nd^ degree burn marked in yellow at 75 µm and onset of 3rd degree burn marked in red at 1200 µm.

Based on the data in Table II and Figure 6, both the flat plate (on the left in Figure 6) and the selected sensors on the manikin (on the right) predict second degree burns under the conditions tested for all three systems/materials employed in the V&V testing. The differences in predicted performance for the three systems/materials are small compared to the variability, which is indicated by the error bars representing ± one standard deviation from the mean.

The variability is especially pronounced in the manikin tests. It should be noted that some of this variability arises from the depth of burn calculation and not from the inherent variability of the transmitted heat flux. This becomes clear when the variability in the depth of burn data for the manikin tests shown in Figure 6 is compared to the variability in the directly measured transmitted fluence and ETF (normalized transmitted fluence) for the same manikin tests shown in Figures 8 and 9. It should be noted that when depth of burn data is reported as only second or third degree burn injury, the high variability observed in the depth of burn may be obscured.

Reporting the depth of burn in addition to burn injury in Figure 6 allows a more detailed understanding of the predicted injury and comparison between the flat plate and manikin results. Although average depth of burn for the manikin and the flat plate both lie within the dermis (from 75 to 1200 μm) for all the systems/materials, the flat plate predicts a somewhat deeper second degree burn than the manikin. The predicted burn injury for the Midscale cylinder (in the middle of Figure 6) is higher than that for the flat plate, with an average depth of burn over 1200 μm (third degree burns) for all three systems/materials tested.

The differences in results from the three different test methods probably reflect the differences in the air gap that is present between the protective fabric and the sensor surface in each case. Extensive testing of transmitted heat flux through a wide range of fabrics using the CO_2 laser [5] has indicated that the thickness of the air gap has a very strong effect on the results. This effect is well known in the FR testing community [6, 7] and is reflected in the use of a defined spacer in the TPP test.

An air gap between the fabric and the sensor acts as an insulating layer that provides significant additional protection against transmitted fluence. On the F1930 manikin, there is a significant air gap at all the selected sensor locations as shown in Figure 5. The manikin air gap is large enough that the fabric is unlikely to come into immediate contact with the selected sensors during flame engulfment. By comparison, as indicated in Figure 7, the method used to clamp the fabric on the flat plate test form allows some air gap, but less than that observed for the ensemble on the manikin. The clamping method employed for the cylindrical test form as shown in Figure 7 produces a very close fit of the material to the test form without any measurable air gap between the fabric and the sensor.

The absence of an air gap in the cylindrical test form corresponds to a very tight fitting single layer garment, making it a worst case scenario for FR protection. Although there are situations in which testing with the cylindrical form would be preferred [2], it should not be used to predict

manikin performance in regions with a single layer of fabric unless care is taken to provide a comparable air gap on the cylinder to that on the manikin.

Figure 7. Fabric specimens clamped onto the flat plate and cylindrical test forms

Based on these results, a new clamping system is being developed for the flat plate test form, which will allow this effect to be explored by performing the testing as a function of a controlled air gap. Using the new clamping system, it will be possible to carry out a series of Midscale flat plate measurements with systematic variation in air gap to determine the effect of air gap on % burn injury, depth of burn, transmitted fluence and ETF. It should also be possible to establish what air gap might be used on the Midscale flat plate to match the manikin results, if desired. If these results are successful, a similar spacing system may be designed and implemented for the Midscale cylindrical test form as well.

Table III and Figure 8 show the average transmitted fluence as a function of material/system and test method for all conditions. Although lines corresponding to a predicted second or third degree burn injury do not appear in Figure 8 as they do in Figure 6, a comparison of Figure 6 and Figure 8 suggests that a total fluence of 85-90 kJ/m^2 would in this case correspond to a predicted onset of second degree burn injury and onset of third degree burn would occur just under 200 kJ/m^2.

Table III
Average Transmitted Fluence in kJoules/m^2

	Total Fluence		
	Flat Plate	Cylinder	Manikin
A2Cu	158.4	216.4	122.1
FRACU	159.1	214.2	90.42
iCVC	171.6	205.8	101.8

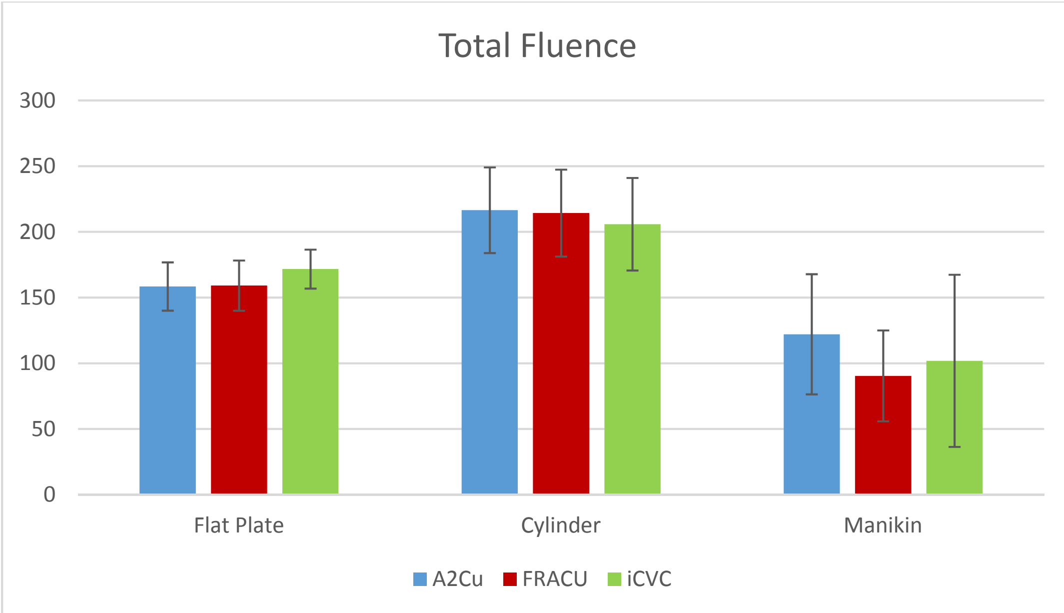

Figure 8. Average transmitted fluence in kJoules/m²

Transmitted fluence is a measure of the total energy per unit area imparted to the surface of the cylinder, flat plate or manikin at a given sensor. Since transmitted fluence does not depend upon any assumptions about local skin thickness or discontinuous calculations of depth of burn within different skin layers, it is a more direct measurement of the thermal energy transmitted through the fabric than depth of burn and % burn injury. If users sought to identify a desired value of transmitted fluence or ETF, they might compare the measured value with the value of a known fabric such as Defender M.

Table IV and Figure 9 show average ETF for all the conditions tested. ETF is a normalized measurement of the transmitted fluence, which is obtained by dividing the transmitted fluence in kJ/m^2 for a 4 s exposure by the fluence in kJ/m^2 measured by a bare sensor at that same location during a 4 s calibration burn.

Table IV
Average ETF

Energy Transmission Factor (Protected Fluence/Bare Fluence)			
	Flat Plate	Cylinder	Manikin
A2Cu	0.4580	0.6187	0.3304
FRACU	0.4623	0.6251	0.2562
iCVC	0.4938	0.5900	0.3078

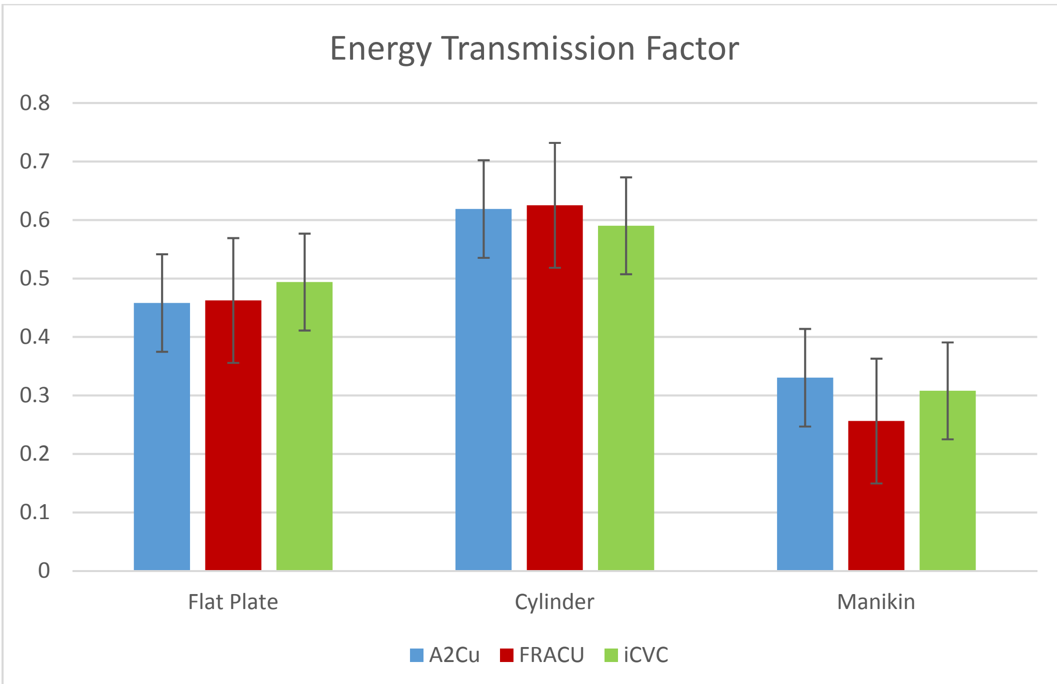

Figure 9. Average ETF

In Figures 7-9 the FRACU material exhibits somewhat poorer relative performance on the cylinder test than on the flat plate and manikin. The tight clamping of the fabric circumferentially on the cylinder may suppress the tendency of the FRACU fabric to balloon out during combustion, which can enhance its protective performance. Additional experimentation would be required to determine if this or other phenomena affect the test results. Close contact with the fabric may also allow the sensors to detect changes occurring in the FRACU fabric as the FR phosphorus additive in the FR rayon is depleted. Between 4 and 5 s of exposure at 84 kW/m^2, the FRACU material exhibits a rapid drop in FR protection due to exhaustion of the additive [8].

Variability of the reported data

The data in Appendix B include Coefficient of Variation (COV) in the transmitted fluence. It is used as a measure of the variability from sensor to sensor within a given test and the variability from test to test within a given test method (cylinder, flat plate or manikin) and system/material (A2CU, FRACU or iCVC). The variability in fluence is a good measure of repeatability of the test because it is not dependent on the nonlinear and discontinuous calculations of burn injury, only on the behavior of the material. COV is the standard deviation divided by the mean times 100 and represents the variability as a % of the mean. Table V is a summary of the measured variability for all materials and systems tested.

Table V
V&V Variability based on Transmitted Fluence at 4 s

Material	Test	Mean Transmitted Fluence/ETF	Test to Test COV	Sensor to Sensor COV
		kJ/m^2/nondimensional	%	%
A2CU	Cylinder	216.4/0.62	10.59	15.13
A2CU	Flat Plate	158.4/0.46	4.76	11.58
A2CU	Manikin	122.1/0.33	4.06	37.30
FRACU	Cylinder	214.3/0.62	7.62	15.49
FRACU	Flat Plate	159.1/0.46	8.10	11.86
FRACU	Manikin	90.4/0.26	9.20	38.07
iCVC	Cylinder	205.8/0.59	9.32	17.11
iCVC	Flat Plate	171.7/0.49	5.44	8.68
iCVC	Manikin	101.8/0.31	4.95	64.08

The values in Table V clearly indicate that mean transmitted fluence and ETF decrease with increasing air gap - highest for the cylinder, lower for the flat plate and lowest for the selected manikin sensors. Test to test variability in the flat plate and the manikin is very close for all three materials tested, although it is higher for both test forms in the FRACU tests.

The sensor to sensor variability for the manikin tests is significantly higher than for the two Midscale test forms. Since the variability in incident heat flux (see Figure 4) is lower for both the Midscale tests than for the manikin, this is to be expected. However, even though the sensor to sensor variability in the manikin is very high (64.08% for the iCVC), the test to test variability for the same test is low (4.95%). This suggests that the sensor to sensor differences are reproducible from test to test.

5. Conclusions and Recommendations

Conclusions

As shown in Appendix B and the summary data, comparison of the Midscale flat plate test results with the F1930 manikin tests shows that both tests predict second degree burn injury (depth of burn between 75 and 1200 µm) according to the F1930. The injury predictions from the cylindrical test form were higher, with third degree burns predicted for all systems/materials.

Although the Midscale test cannot replace the F1930 for assessment of system performance, a comparison of the Midscale flat plate test results with the selected sensor results from the full scale manikin tests demonstrate that some predictions can be made. Based on the data collected, it can reasonably be predicted that a midscale flat plate predicted burn depth associated with a second degree burn (depth of burn between 75 and 1200 µm) would also result in a second degree burn on the select sensor locations for the full scale manikin testing. This is consistent with the depth of burn data reporting that is provided in the ASTM F1930 test.

The size of the insulating air gap between the fabric and the sensor surface was observed to have a significant effect on depth of burn and burn injury. The air gap in the cylindrical test form is minimized by the manner in which the fabric is attached to the form, corresponding in this case to a tight fitting single layer garment. This is a worst case scenario for FR protection and the predicted depth of burn is greatest in the cylinder tests, exceeding the 1200 µm level for third degree burns. Results of the Midscale cylinder test are not generally predictive of the performance of a full ensemble in the F1930 system level test.

All the systems/materials selected for this V&V were designed to provide essentially the same level of FR protection – no predicted third degree burns after 4 s of flame engulfment at 84kW/m^2. As a result, there is limited variation in the measured FR performance of the three systems. In order to support a valid Precision and Bias Statement, systems/materials with greater variability should be tested. Further Midscale testing on materials with a greater range of FR performance will be required to prepare the next draft of the Midscale test method for the ASTM ballot.

ETF has been shown to be a repeatable, normalized indication of the performance of an individual fabric. In this series of V&V tests it has been calculated from the total transmitted fluence at the end of 4 s of exposure at 84 kW/m^2. ETF may also be calculated as a function of time during the test and plotted to provide a fingerprint of the incident heat energy transmitted through a protective fabric during the course of a 4-s flame engulfment. This fingerprint would provide a very useful way to compare the performance of novel FR fabrics with known and proven protective fabrics such as Defender M and Nomex.

Recommendations

- The method of clamping on the flat plate should be modified to allow control of the size of the air gap between the plate surface and the protective fabric. If these results are successful, a similar spacing system could be designed and implemented for the Midscale cylindrical test form as well.
- A series of Midscale flat plate measurements should be caried out with systematic variation in air gap to determine the effect of air gap on % burn injury, depth of burn, transmitted fluence and ETF.
- The V&V testing should be augmented with materials exhibiting significant differences in FR performance to support a Precision and Bias statement for the Midscale test method.
- Army materials and systems should be used for this testing if available. Alternatively, the Marine Corps has provided some materials which may be used for this testing.
- Using the V&V data, curves of ETF as a function time during the flame engulfment should be generated to provide an FR fingerprint for each of the three materials tested.
- These curves could then be compared with similar ETF curves for new materials proposed for adoption for FR garments and other applications.
- Determination of representative skin thicknesses on the head or hands and development of more biofidelic burn injury models reflecting that realistic physiology should be a goal of future research and development.
- Since both the flat plate and cylinder methods are materials tests and are still under development, results obtained from these Midscale tests should not be extrapolated to predict the FR performance of full ensembles using the F1930 test.
- The Midscale test is a quick and cost-effective method for evaluation of FR performance of design features or for observation of material behavior in a flame engulfment scenario to inform future development.

This document reports research undertaken at the U.S. Army Natick Soldier Research, Development and Engineering Center, Natick, MA, and has been assigned No. NATICK/TR- 17/004 in a series of reports approved for publication.

6. References

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Appendix A
Midscale Test Method TTA
(Reprint of original)

DEPARTMENT OF THE ARMY
US ARMY RESEARCH, DEVELOPMENT AND ENGINEERING COMMAND
NATICK SOLDIER RD&E CENTER
KANSAS STREET
NATICK MA 01760-

RDNS-ADT

Collaborative Science & Technology Planning (CSTP)
Technology Transition Agreement (TTA)
Between
Project Manager Soldier Clothing & Individual Equipment (PM-SCIE)
And
Warfighter Science, Technology and Applied Research Directorate (WarSTAR), Natick Soldier Research, Development & Engineering Center (NSRDEC)

Subject: Transition of Mid-Scale Flame Resistant (FR) Test System

1. Overview. PEO Soldier and NSRDEC hereby mutually agree to enter into this TTA for the purpose of defining technology deliverables from the Mid-Scale Flame Resistant (FR) Test System project. The purpose of this TTA is to document a clear understanding between both parties of the conditions required to ensure a successful transition of testing capabilities that will be available at the NSRDEC Ouellette Thermal Test Facility (TTF) for PM-SCIE to utilize to evaluate materials, garments and individual Soldier equipment. This capability could support multiple PM-SCIE clothing and individual equipment (CIE) programs and projects.

2. NSRDEC responsibilities.

   a. Technology products to be delivered: WarSTAR will develop a mid-scale FR test apparatus and test method capable of assessing multiple aspects of performance relative to clothing items and equipment that require flame resistance. Project will result in a new mid-scale test apparatus and method for assessing durability and flame resistance on mock-up garment constructions/systems that can be tested on a smaller scale prior to full-scale ASTM F1930 testing, to provide an indication of results that will be seen during full mannequin testing. Orientation and configuration of materials in prototype system will be similar to actual wear conditions and data is expected to correlate to full-scale testing.

   b. Project metrics are shown in the table below.

Measure	Current Status	Effort Objective	Army Objective	TRL
Cost	Approximately $2000/set-up $450/test plus garment cost	50% decrease in cost	More cost effective FR testing	Start – TRL 3 End – TRL 5
Schedule/Time	3 tests per hour	25% decrease in time	More rapid testing	Start – TRL 2 End – TRL 5
Measure	Current Status	Effort Objective	Army Objective	TRL

Ability to use a single test to evaluate multiple aspects of field performance	Not possible	Possible	To simulate more realistic field conditions during test and evaluation of new approaches to protection	Start – TRL 3 End – TRL 5

c. Delivery schedule. Testing capability will be available to PM-SCIE at NSRDEC by the end of FY13.

3. PEO Soldier responsibilities.

a. Integration strategy.

(1) Upon successful demonstration of key performance requirements (ability to demonstrate the correlation of the developed mid-scale test with ASTM F1930 instrumented manikin test), PM-SCIE intends to leverage the mid-scale flame resistant (FR) test system and utilize the NSRDEC Ouellette Thermal Test Facility for multiple on-going and next generation clothing and individual equipment (CIE) projects and programs under PE 643827.S53 and PR 654601.S60.

b. Risk analysis.

(1) A mid-scale FR test that will have the ability to support and predict the technical testing requirement results associated with each FR clothing item as specified in the individual Purchase Description (PD) and will significantly reduce RDT&E timelines. Additionally these evaluations should support the Key Performance Parameters (KPPs) and Key System Attributes (KSAs) that support the thresholds and objectives outline in the applicable Capability Development Documents (CDD) (e.g., Core Soldier CDD) and the Capability Production Documents (CPDs) (e.g., Army Combat Shirt and FR Fuel Handler's Coverall CPDs).

(2) PM-SCIE intends to encourage a collaborative environment with its other FR testing partners (North Carolina State University) during this project.

(3) PM-SCIE will also consider providing additional funding (PE 643827.S53 and PR 654601.S60, as appropriate) to further support this project.

4. Periodic review.

a. Current programmatic activities and overall status provided to PM-SCIE at least on a quarterly basis, prior to the Product Manager's scheduled quarterly review.

b. This TTA will be reviewed annually by PM-SCIE and NSRDEC for potential renegotiation resulting from issues such as changes in funding, deliverables, technology development issues, or Mid-Scale Flame Resistant (FR) Test System program changes.

5. Points of contact.

a. NSRDEC S&T Project Officer: Ms. Peggy Auerbach, Textile Technologist, Margaret.auerbach@us.army.mil, 508-233-4074.

b. PEO-Soldier Project Engineer: Ms. Celia Powell, Project Engineer, celia.powell@us.army.mil, 508-233-5802.

Concurrence:

Celia S Powell 17 Sep 10
Celia Powell Date
Project Engineer, PM-SCIE

17 Sep 10
Jeffrey Myhre Date
Assistant Product Manager
PM-SCIE, PEO-Soldier

20 SEP 10
Michael E. Sloane, LTC Date
PM-SCIE

17 Sept 10
Margaret Auerbach Date
Textile Technologist
WarSTAR, NSRDEC

Margaret E. Roylance 17 Sep 10
Margaret E. Roylance Date
Chief, Materials &
Defense Science Division
WarSTAR, NSRDEC

Approval:

20 SEP 10
William E. Cole, COL Date
PM-SPIE
PEO-Soldier

John J. Gassner 17 Sep 10
John J. Gassner Date
Director, WarSTAR
NSRDEC

CF:
PEO-Soldier G7 (T.J.Junor)
NSRDEC/PEO-Soldier Liaison (K.Gerstein)
NSRDEC (T. Mattus)
NSRDEC (H. Girolamo)

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Appendix B
Midscale V&V Data Summary

Test #	Date	Material	Target	Burn Injury (%)			Depth of Burn (μ)	Transmitted Fluence (kJ/m^2)			Bare Fluence** (kJ/m2)	Energy Transmission Factor
				2nd	3rd	total	mean	Mean	Std	Cv (%)		
1	12/10/2014	A2CU	Cylinder	17.39	82.61	100.00	1498.3	221.1	33.906	15.34%	364.7	0.6063
13	12/11/2014	A2CU	Cylinder	0.00	100.00	100.00	1869.1	263.7	45.134	17.12%	362.4	0.7276
20	12/11/2014	A2CU	Cylinder	0.00	100.00	100.00	1735.1	246.8	29.740	12.05%	362.4	0.6810
30	12/18/2014	A2CU	Cylinder	39.13	56.52	95.65	1093.8	182.6	34.295	18.78%	312.6	0.5841
37	12/22/2014	A2CU	Cylinder	4.35	95.65	100.00	1570.8	228.5	40.772	17.84%	333.1	0.6860
39	12/23/2014	A2CU	Cylinder	13.04	86.96	100.00	1578.3	230.90	37.633	16.30%	306.0	0.7546
47	12/30/2014	A2CU	Cylinder	4.35	95.65	100.00	1577.7	230.1	28.340	12.32%	368.3	0.6248
54	12/30/2014	A2CU	Cylinder	56.52	43.48	100.00	1071.4	179.7	23.664	13.17%	368.3	0.4879
58	4/3/2015	A2CU	Cylinder	43.48	56.52	100.00	1130.5	186	33.085	17.79%	382.4	0.4864
73	4/8/2015	A2CU	Cylinder	30.43	69.57	100.00	1220.7	193.9	32.780	16.91%	330.6	0.5865
93	4/10/2015	A2CU	Cylinder	21.74	78.26	100.00	1334.2	204.8	34.160	16.68%	342.8	0.5974
98	4/10/2015	A2CU	Cylinder	8.70	91.30	100.00	1477.7	219	29.981	13.69%	342.8	0.6389
119	4/14/2015	A2CU	Cylinder	17.39	82.61	100.00	1360.4	206.5	28.953	14.02%	367.1	0.5625
123	4/15/2015	A2CU	Cylinder	4.35	95.65	100.00	1653.4	237.2	31.726	13.38%	354.1	0.6699
124	4/15/2015	A2CU	Cylinder	21.74	78.26	100.00	1345.7	205.2	35.190	17.15%	354.1	0.5795
128	4/15/2015	A2CU	Cylinder	21.74	78.26	100.00	1383.3	208.9	31.331	15.00%	354.1	0.5899
129	4/15/2015	A2CU	Cylinder	8.70	91.30	100.00	1438.3	214	27.263	12.74%	354.1	0.6043
131R	4/15/2015	A2CU	Cylinder	0.00	100.00	100.00	1647.9	237.1	28.621	12.07%	354.1	0.6696
Average							1443.7	216.4		15.13%	350.8	0.6187
Cv								10.59%				
2	12/10/2014	A2CU	Flat Plate	100.00	0.00	100.00	709	165.7	19.091	11.52%	328.8	0.5040
21	12/11/2014	A2CU	Flat Plate	92.31	7.69	100.00	665.8	162.7	22.385	13.76%	338.8	0.4802
31	12/18/2014	A2CU	Flat Plate	100.00	0.00	100.00	652.6	163.1	19.147	11.74%	323.3	0.5045
38	12/22/2014	A2CU	Flat Plate	92.31	7.69	100.00	620.9	160.80	20.658	12.85%	343.70	0.4678
43	12/23/2014	A2CU	Flat Plate	92.31	7.69	100.00	712.9	164.80	21.594	13.10%	342.10	0.4817
48	12/30/2014	A2CU	Flat Plate	92.31	7.69	100.00	754.2	166.8	19.688	11.80%	359.2	0.4644
55	12/30/2014	A2CU	Flat Plate	100.00	0.00	100.00	573.5	161.1	14.606	9.07%	359.2	0.4485
60	4/6/2015	A2CU	Flat Plate	92.31	7.69	100.00	654.6	159.7	22.560	14.13%	354.9	0.4500
66	4/6/2015	A2CU	Flat Plate	92.31	7.69	100.00	656.3	162.9	18.716	11.49%	354.9	0.4590
78	4/8/2015	A2CU	Flat Plate	100.00	0.00	100.00	633.7	158.8	20.125	12.67%	348	0.4563
83	4/9/2015	A2CU	Flat Plate	100.00	0.00	100.00	426.8	149.3	17.514	11.73%	348	0.4290
87	4/9/2015	A2CU	Flat Plate	100.00	0.00	100.00	614.9	161.1	20.567	12.77%	348	0.4629
106	4/13/2015	A2CU	Flat Plate	92.31	7.69	100.00	733.4	166.7	19.008	11.40%	344.9	0.4833
107	4/13/2015	A2CU	Flat Plate	100.00	0.00	100.00	389.2	144.3	12.767	8.85%	344.9	0.4184
110	4/13/2015	A2CU	Flat Plate	100.00	0.00	100.00	355.3	141.5	13.179	9.31%	344.9	0.4103
111	4/14/2015	A2CU	Flat Plate	100.00	0.00	100.00	483.2	151.9	16.499	10.86%	348.7	0.4356

Test #	Date	Material	Target	Burn Injury (%)			Depth of Burn (μ)	Transmitted Fluence (kJ/m^2)			Bare Fluence** (kJ/m2)	Energy Transmission Factor
				2nd	3rd	total	mean	Mean	Std	Cv (%)		
113	4/14/2015	A2CU	Flat Plate	100.00	0.00	100.00	515.2	152	17.300	11.38%	348.7	0.4359
115	4/14/2015	A2CU	Flat Plate	100.00	0.00	100.00	582.9	158	15.847	10.03%	348.7	0.4531
Average							596.4	158.4		11.58%	346.1	0.4581
Cv								4.76%				
3	12/10/2014	A2CU	Manikin	43.62	6.31	49.93	371.4	122.9	41.694	33.93%	359.5	0.3419
12	12/11/2014	A2CU	Manikin	49.93	6.29	56.22	308.5	116.4	39.644	34.06%	359.9	0.3234
19	12/11/2014	A2CU	Manikin	43.33	12.79	56.12	423.5	128.5	52.567	40.91%	359.9	0.3570
79	4/8/2015	A2CU	Manikin	56.48	6.21	62.69	409.8	125.3	56.326	44.95%	370.6	0.3381
84	4/9/2015	A2CU	Manikin	50.12	12.49	62.61	400.7	123.3	47.116	38.21%	378.7	0.3256
134	4/16/2015	A2CU	Manikin	56.33	0.00	56.33	269.9	116	36.844	31.76%	391.7	0.2961
Average							364.0	122.1		37.30%	370.1	0.3304
Cv								4.06%				
7	12/10/2014	FRACU	Cylinder	4.35	95.65	100.00	1672.2	239.9	30.165	12.57%	364.7	0.6578
25	12/18/2014	FRACU	Cylinder	13.04	86.96	100.00	1447.7	216.2	35.321	16.34%	312.6	0.6916
27	12/18/2014	FRACU	Cylinder	13.04	86.96	100.00	1405.9	210.9	31.589	14.98%	312.6	0.6747
28	12/18/2014	FRACU	Cylinder	13.04	86.96	100.00	1529	224.9	33.309	14.81%	312.6	0.7194
36	12/22/2014	FRACU	Cylinder	17.39	82.61	100.00	1412.6	211.7	35.324	16.69%	333.1	0.6355
44	12/23/2014	FRACU	Cylinder	13.04	86.96	100.00	1520.6	223.70	39.658	17.73%	306.0	0.7310
49	12/30/2014	FRACU	Cylinder	56.52	43.48	100.00	949	168.9	31.778	18.81%	368.3	0.4586
51	12/30/2014	FRACU	Cylinder	39.13	60.87	100.00	1220.3	193.1	33.171	17.18%	368.3	0.5243
57	4/3/2015	FRACU	Cylinder	4.35	95.65	100.00	1552.1	225.5	26.007	11.53%	382.4	0.5897
74	4/8/2015	FRACU	Cylinder	17.39	82.61	100.00	1471.2	217.8	40.581	18.63%	330.6	0.6588
75	4/8/2015	FRACU	Cylinder	8.70	91.30	100.00	1419.7	211.4	31.667	14.98%	330.6	0.6394
95	4/10/2015	FRACU	Cylinder	4.35	95.64	99.99	1684.6	242.3	43.324	17.88%	342.8	0.7068
96	4/10/2015	FRACU	Cylinder	21.74	78.26	100.00	1366.4	209.3	41.021	19.60%	342.8	0.6106
118	4/14/2015	FRACU	Cylinder	8.70	91.30	100.00	1388.4	208.7	28.587	13.70%	367.1	0.5685
120	4/14/2015	FRACU	Cylinder	8.70	91.30	100.00	1468.9	217.5	27.383	12.59%	367.1	0.5925
121	4/15/2015	FRACU	Cylinder	13.04	86.96	100.00	1381.2	208.3	27.648	13.27%	354.1	0.5883
122	4/15/2015	FRACU	Cylinder	26.09	73.91	100.00	1365.8	205.9	29.187	14.18%	354.1	0.5815
127	4/15/2015	FRACU	Cylinder	8.70	91.30	100.00	1494	220.6	29.361	13.31%	354.1	0.6230
Average							1430.5	214.3		15.49%	344.7	0.6251
Cv								7.62%				
8	12/10/2014	FRACU	Flat Plate	100.00	0.00	100.00	534	155.1	15.661	10.10%	328.8	0.4717
18	12/11/2014	FRACU	Flat Plate	100.00	0.00	100.00	611.2	158.2	16.412	10.37%	338.8	0.4669

Test #	Date	Material	Target	Burn Injury (%)			Depth of Burn (μ)	Transmitted Fluence (kJ/m^2)			Bare Fluence** (kJ/m2)	Energy Transmission Factor
				2nd	3rd	total	mean	Mean	Std	Cv (%)		
26	12/18/2014	FRACU	Flat Plate	66.67	33.33	100.00	1025.4	181.6	52.049	28.66%	323.3	0.5617
29	12/18/2014	FRACU	Flat Plate	100.00	0.00	100.00	430.6	155.9	27.561	17.68%	323.3	0.4822
42	12/23/2014	FRACU	Flat Plate	92.31	7.69	100.00	621.3	162.40	23.964	14.76%	342.10	0.4747
50	12/30/2014	FRACU	Flat Plate	84.62	15.38	100.00	835.3	169.8	18.858	11.11%	359.2	0.4727
62	4/6/2015	FRACU	Flat Plate	100.00	0.00	100.00	684.5	159.7	13.946	8.73%	354.9	0.4500
63	4/6/2015	FRACU	Flat Plate	100.00	0.00	100.00	468.2	147.8	13.530	9.15%	354.9	0.4165
68	4/6/2015	FRACU	Flat Plate	69.23	30.77	100.00	923.7	174.8	17.287	9.89%	354.9	0.4925
69**	4/7/2015	FRACU	Flat Plate	84.62	15.38	100.00	739.1	168.6	22.219	13.18%	358.4	0.4704
82B**	4/8/2016	FRACU	Flat Plate	84.62	15.38	100.00	1042	179.4	6.920	3.86%	348	0.5155
89	4/9/2015	FRACU	Flat Plate	92.31	7.69	100.00	545.4	159.5	23.047	14.45%	349.4	0.4565
92	4/9/2015	FRACU	Flat Plate	100.00	0.00	100.00	400.5	151.2	21.323	14.10%	349.4	0.4327
99	4/10/2015	FRACU	Flat Plate	100.00	0.00	100.00	526.5	158	19.886	12.59%	335.1	0.4715
102	4/13/2015	FRACU	Flat Plate	100.00	0.00	100.00	503.9	149.5	12.080	8.08%	344.9	0.4335
103	4/13/2015	FRACU	Flat Plate	100.00	0.00	100.00	697.7	160.4	10.636	6.63%	344.9	0.4651
105	4/13/2015	FRACU	Flat Plate	100.00	0.00	100.00	219.9	130.9	11.276	8.61%	344.9	0.3795
109	4/13/2015	FRACU	Flat Plate	100.00	0.00	100.00	389.2	140.9	16.344	11.60%	344.9	0.4085
Average							622.1	159.1		11.86%	344.5	0.4623
Cv								8.10%				
9	12/10/2014	FRACU	Manikin	22.90	0.00	22.90	66	85.2	26.755	31.40%	343.3	0.2482
16	12/11/2014	FRACU	Manikin	18.48	0.00	18.48	59.3	80.8	29.638	36.68%	349.4	0.2313
70B**	4/7/2015	FRACU	Manikin	36.46	0.00	36.46	88.4	94.6	29.557	31.24%	348.8	0.2712
88	4/9/2015	FRACU	Manikin	4.45	0.00	4.45	122.8	87.2	37.644	43.17%	361.2	0.2414
136	10/8/2015	FRACU	Manikin	32.78	0.00	32.78	121.7	90.2	37.326	41.38%	357	0.2527
137	10/8/2015	FRACU	Manikin	42.07	0.00	42.07	227.5	104.5	46.566	44.56%	357	0.2927
Average							114.3	90.4		38.07%	352.8	0.2562
Cv								9.20%				
4	12/10/2014	iCVC	Cylinder	17.39	82.61	100.00	1506.3	223	40.029	17.95%	364.7	0.6115
17	12/11/2014	iCVC	Cylinder	26.09	73.91	100.00	1284.5	200.8	32.748	16.31%	362.4	0.5541
23	12/11/2014	iCVC	Cylinder	8.70	91.30	100.00	1609	233.5	34.746	14.88%	362.4	0.6443
34	12/22/2014	iCVC	Cylinder	47.83	52.17	100.00	1282.8	201.5	42.459	21.07%	333.1	0.6049
41	12/23/2014	iCVC	Cylinder	60.87	39.13	100.00	1060.7	178.10	22.666	12.73%	306.0	0.5820
45	12/30/2014	iCVC	Cylinder	34.78	65.22	100.00	1240.5	197	36.737	18.65%	368.3	0.5349
52	12/30/2014	iCVC	Cylinder	13.04	86.96	100.00	1445.6	216.9	38.026	17.53%	368.3	0.5889
59	4/3/2015	iCVC	Cylinder	26.09	73.91	100.00	1255.4	199.6	44.851	22.47%	382.4	0.5220
71	4/8/2015	iCVC	Cylinder	56.52	43.48	100.00	1044.5	178.3	30.849	17.30%	330.6	0.5393

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72	4/8/2015	iCVC	Cylinder	8.70	91.30	100.00	1524.9	223.1	33.856	15.18%	330.6	0.6748
76	4/8/2015	iCVC	Cylinder	39.13	60.87	100.00	1122.1	185.8	37.273	20.06%	330.6	0.5620
77	4/8/2015	iCVC	Cylinder	21.74	78.26	100.00	1340	204.3	35.034	17.15%	330.6	0.6180
94	4/10/2015	iCVC	Cylinder	8.70	91.30	100.00	1631.9	236.1	38.600	16.35%	342.8	0.6887
97	4/10/2015	iCVC	Cylinder	17.39	82.61	100.00	1362.8	207.2	31.724	15.31%	342.8	0.6044
117	4/14/2015	iCVC	Cylinder	8.70	91.30	100.00	1604.6	232	37.785	16.29%	367.1	0.6320
125	4/15/2015	iCVC	Cylinder	47.83	52.17	100.00	1140.5	185.7	26.316	14.17%	354.1	0.5244
126	4/15/2015	iCVC	Cylinder	56.52	43.48	100.00	1099	183.1	28.688	15.67%	354.1	0.5171
130	4/15/2015	iCVC	Cylinder	21.74	78.26	100.00	1465.1	218.6	41.420	18.95%	354.1	0.6173
Average							1334.5	205.8		17.11%	349.2	0.5900
Cv								9.32%				
5	12/10/2014	iCVC	Flat Plate	84.62	15.38	100.00	931.1	180.4	13.904	7.71%	328.8	0.5487
14	12/11/2014	iCVC	Flat Plate	100.00	0.00	100.00	660.1	164.9	15.882	9.63%	338.8	0.4867
35	12/22/2014	iCVC	Flat Plate	92.31	7.69	100.00	609.3	167.2	12.412	7.42%	343.7	0.4865
40	12/23/2014	iCVC	Flat Plate	92.31	7.69	100.00	570.1	167.50	20.851	12.45%	342.10	0.4896
46	12/30/2014	iCVC	Flat Plate	100.00	0.00	100.00	727.8	174.3	17.207	9.87%	359.2	0.4852
53	12/30/2014	iCVC	Flat Plate	100.00	0.00	100.00	605.5	167.4	11.706	6.99%	359.2	0.4660
61	4/6/2015	iCVC	Flat Plate	100.00	0.00	100.00	820	176.2	14.540	8.25%	354.9	0.4965
65	4/6/2015	iCVC	Flat Plate	69.23	30.77	100.00	959.2	184.1	14.545	7.90%	354.9	0.5187
67	4/6/2015	iCVC	Flat Plate	100.00	0.00	100.00	714.6	171.8	12.037	7.01%	354.9	0.4841
80	4/8/2015	iCVC	Flat Plate	100.00	0.00	100.00	404.2	153.9	14.155	9.20%	348.0	0.4422
85	4/9/2015	iCVC	Flat Plate	100.00	0.00	100.00	925.3	183.9	17.554	9.55%	349.4	0.5263
100	4/13/2015	iCVC	Flat Plate	100.00	0.00	100.00	870.8	180	12.322	6.85%	344.9	0.5219
101	4/13/2015	iCVC	Flat Plate	69.23	30.77	100.00	995	186.5	14.063	7.54%	344.9	0.5407
104	4/13/2015	iCVC	Flat Plate	100.00	0.00	100.00	453.1	153.8	15.750	10.24%	344.9	0.4459
108	4/13/2015	iCVC	Flat Plate	100.00	0.00	100.00	727.8	171.7	13.533	7.88%	344.9	0.4978
112	4/14/2015	iCVC	Flat Plate	100.00	0.00	100.00	633.7	166.4	19.070	11.46%	348.7	0.4772
114	4/14/2015	iCVC	Flat Plate	100.00	0.00	100.00	658.2	167.1	13.920	8.33%	348.7	0.4792
116	4/14/2015	iCVC	Flat Plate	100.00	0.00	100.00	757.9	172.7	13.740	7.96%	348.7	0.4953
Average							723.5	171.7		8.68%	347.8	0.4938
Cv								5.44%				
6	12/10/2014	iCVC	Manikin	44.10	0.00	44.10	257.6	97.5	54.478	55.87%	320.5	0.3042
15	12/11/2014	iCVC	Manikin	33.21	0.00	33.21	309.4	99.4	58.332	58.68%	339	0.2932
22	12/11/2014	iCVC	Manikin	32.96	11.15	44.11	263.7	97.8	53.591	54.80%	339	0.2885
81	4/8/2015	iCVC	Manikin	33.82	10.99	44.81	411	102	72.164	70.75%	337.7	0.3020

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86	4/9/2015	iCVC	Manikin	22.80	22.80	45.60	488.2	111	74.484	67.10%	331.9	0.3344
133	4/16/2015	iCVC	Manikin	22.80	22.80	45.60	445	103.3	79.828	77.28%	318.2	0.3246
Average							362.5	101.8		64.08%	331.1	0.3078
Cv								4.95%				